



**Rating of Hearing Protector Performance  
for Impulse Noise  
(Reprint)**

**By**

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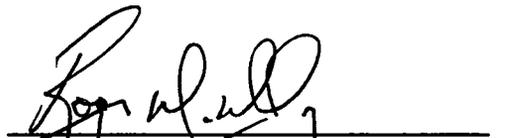
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## Rating of Hearing Protector Performance for Impulse Noise

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**Abstract.** Concern has often been expressed that the performance of hearing protectors in steady noise may not apply to their performance in impulse noise. Our current studies, as well as other studies, support the fact that there is a large difference in performance. In all cases, the performance of a protector is much better for impulse noise than for continuous noise. For example, we are obtaining at least 20 dB of protection for hearing protectors with a Noise Reduction Rating (NRR) of essentially zero. We believe that it is not the NRR procedure at fault; but the fact that, for impulse noise, A-weighting does not discriminate enough against low-frequency energy.

### Introduction

The amount of protection provided by hearing protectors in an impulsive noise field is difficult to estimate. Part of this difficulty stems from the fact that most damage-risk criteria use the peak sound pressure level as the main measurement parameter.<sup>1</sup> As we will show, reduction of the peak level may be only 7-12 dB. Yet, the effective protection, based on the reduction of temporary threshold shift (TTS) of hearing between protected and unprotected ears, can be greater than 30 dB.

### Pressure Measurements

#### Reduction of Peak Sound Pressure Under a Hearing Protector (RACAL Muff)

In a current study, 96 subjects have been exposed to levels as high as 100 impulses at 1-minute intervals of 187 dB (A-duration: 3 ms).<sup>5</sup> Two versions of an ear muff manufactured by RACAL, capable of fitting under a military helmet, were used. The two versions differed only in that one was modified by eight, 2.3-mm diameter tubes placed through the seal so as to simulate air leaks that would result from a very poorly fitted muff. The attenuation curves of the two versions of the muff used are

shown in Figure 1. Note that the modified muff (the muff with the holes) actually amplifies the sound in the range of 160-250 Hz.

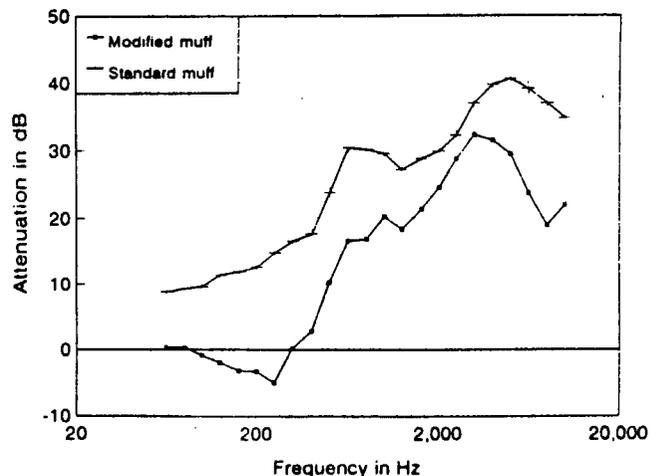


Figure 1. Attenuation of the standard RACAL muff versus the RACAL muff modified by intentional leaks.

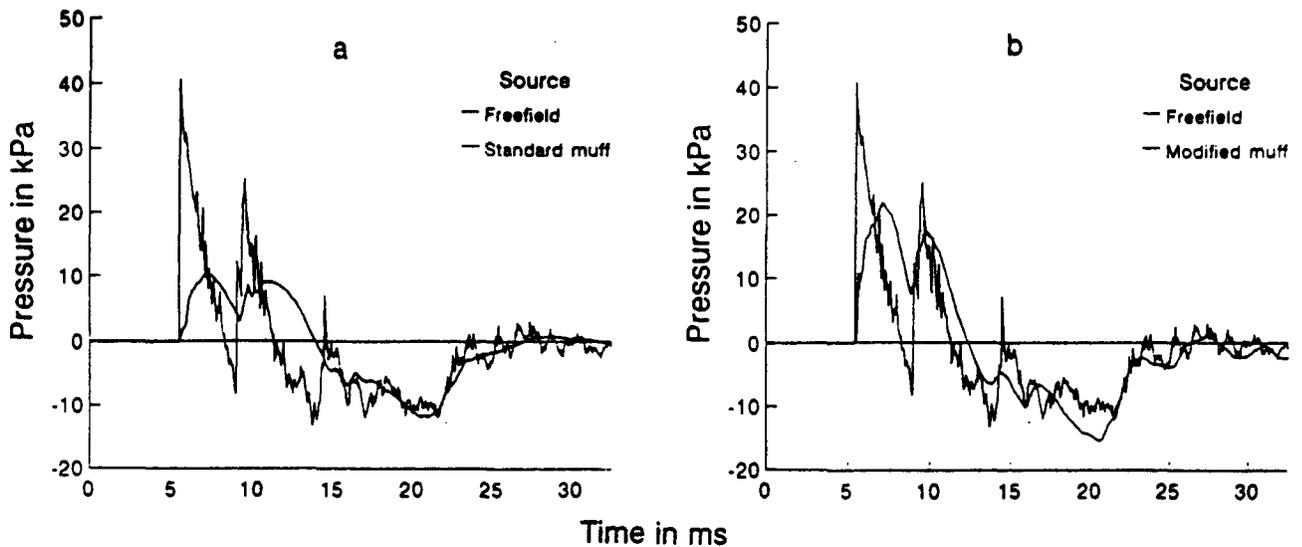


Figure 2. Typical waveforms from free-field measurements away from subjects versus measurements made under the RACAL muff.

**Modification of the Waveform of the Impulse**

Typical waveforms measured outside and under the two type protectors are shown in Figure 2. In these figures, the waveform outside the muff rises to an initial peak pressure and decays to below baseline with an A-duration of about 3 ms and a B-duration of approximately 20 ms. This is followed by a second peak due to the ground reflection (not essential to our argument). The measurements were taken using the authors as subjects. While most of our under-the-muff measurements were made at 186 dB (40 kPa), limited measurements of 182, 188, and 190 dB show very similar results. The waveform under the standard muff (the muff without any holes in the seal) shows a reduction of about 12 dB in the initial peak pressure. Note how the shock front is eliminated. In fact, the waveform looks more like one cycle of a sine wave. In the modified muff, however, the deliberate air leaks make two changes. First, the attenuation of the peak level is reduced to only about 8 dB. Second, some of the shock front is evident before the maximum pressure is reached. Because of this shock front, we would expect this impulse to act similar to an exposure of an unprotected ear at 175 dB. As we will show, this was not the case.

**Results of Current Study**  
**Using Modified and Unmodified Muffs**

**Unmodified Muffs.** The exposure of up to 100 impulses 1-minute apart at a level of 187 dB and a 3-ms A-duration produced virtually no TTS at any frequency in subjects wearing the unmodified RACAL muff. The lack of TTS resulted in a hearing protector modification so more TTS would occur. It was for this reason the RACAL muff was modified by put-

ting eight tubes through the cushion so as to simulate a muff that did not have a good seal.

**Modified Muff.** As a result of using this leaking modified muff, one subject out of 57 did have TTS early in the exposure sequence so that he was not allowed to reach the exposure condition of 100 impulses at 187 dB. Aside from this subject, the amount of TTS of the other subjects was minimal as shown in Table 1. With these results in mind, we now need to find unprotected exposures that resulted in comparable TTS.

**Expected TTS from CHABA and Past Exposures of the Unprotected Ear**

It is not possible to exactly match the data from Table 1; but where a close match is not possible, we will find some data points which provide either similar or more TTS than that which we show in Table 1.

The CHABA criterion provides one comparison. The CHABA criterion limits the peak of a waveform with a 2.9-ms A-duration to 152 dB for 100 impulses. (Note that, if we used the B-duration criterion, the limit would drop to 142 dB.) This criterion was set so that no more TTS than 20 dB for 5 percent of the subjects for any frequency above 3 kHz would be caused. This 20 dB TTS just matches 20 dB TTS at 8 kHz of Table 1. A study from Kryter and Garinther<sup>2</sup> provides a second data point. They have reported that, for 100 impulses with a peak level of 159 dB, the average TTS at 1, 2, and 3 kHz was over 10 dB for 25 percent of 30 subjects. Table 1 shows that the corresponding 25 percentile for the average TTS at 1, 2 and 3 kHz in our data was only 3 dB. Thus, the unprotected exposures at 159 dB produced slightly greater TTS.

Table 1. TTS of 57 Subjects Exposed to 100 Impulses of 187 dB and an A-duration of 3 ms.

Frequency in kHz	Average TTS in dB	TTS in dB Exceeded by		
		5% of Subjects	10% of Subjects	25% of Subjects
1,2,3	1.6	9	7	3
1	2.2	12	8	5
2	1.5	10	6	4
3	1.0	7	6	3
4	1.2	9	7	4
6	1.6	14	6	2
8	2.8	20	11	4
Normal Variability	-	6.4	5	3

**Effective Attenuation Based on TTS**

**Using Peak Level Reduction**

**Modified Muffs.** For the waveforms with 187 dB peak levels as used in our current study, we are obtaining TTS that is less than an open ear exposure of 159 dB. The difference between 187 dB and 159 dB is 28 dB. Since the amount of TTS from our current study is less than the Kryter and Garinther study<sup>2</sup>, this 28 dB is a conservative estimate and the amount of protection is probably larger. For instance, using the same argument for the CHABA criterion, we would obtain 35 dB (187 minus 152) using the A-duration criterion or 45 dB (187 minus 142) using the B-duration criterion. This 28 to 45 dB difference, we claim, is the effective protection provided by the muff. Thus, there is at least 20 dB, and perhaps as much as 37 dB, more protection provided by modified muffs than would be indicated by measuring 8 dB difference between the peak outside and inside the muff.

**Unmodified Muff.** The level at which virtually no TTS occurs for impulse noise has not been accurately determined, however, using Kryter's and Garinther's projection<sup>2</sup>, the range between 140 and 150 dB is probably a reasonable estimate. If this is the case, subtracting 150 dB from 187 dB would indicate an effective reduction as much as 37 dB (47 dB if 140 dB threshold is used) as compared to the 13 dB measured. Clearly, for the type of waveforms we have used, measuring the unweighted peak under the protector dramatically underestimates the protection given.

**Using A-Weighted Energy Reduction**

Another approach for evaluating the effectiveness of hearing protection is to use the reduction of A-weighted energy as a

measure of hearing protector performance. One hundred impulses of 187 dB produced an open ear exposure proportional to an 8-h A-weighted exposure of 133 dB. We have estimated the exposure under the modified muff to be about 118 dB. Likewise, we have estimated the exposure under the unmodified muff to be about an A-weighted exposure of 110 dB. Using this approach, the unmodified muff will have 23 dB of attenuation while the modified muff will show 15 dB of attenuation. Using TTS as an indicator, the amount of TTS for the modified muff is less than what has been observed from 8 h of broadband noise at 85 dBA.<sup>3</sup> Thus, a conservative estimate of the effective attenuation of the modified muff can be made by subtracting 85 dBA from 133 dBA. This effective attenuation again appears to be as much as 48 dB. The effective attenuation of the unmodified muff must be even more.

If we calculate the NRR values of the RACAL muffs and assume the standard deviation is 0, we obtain an NRR of 9 for the modified muff and an NRR of 24 for the unmodified muff. If we use 2 standard deviations, as required by the NRR calculations, the values drop to approximately 1 dB and 14 dB, respectively. Thus, NRR in its present form, obviously, does not work either for evaluating performance of hearing protectors for impulse noise.

**Discussion**

Clearly, the performance of hearing protectors for steady noises drastically differs from their performance for impulse noise. It is clear, also, that the peak level under the muff is not a good measure of the hazard of impulse noise. The wave under the muff has lost the shock front and much of the damaging potential of the higher frequencies.

A-weighted energy is an improvement over the peak levels by about 7 dB in that



Figure 3. A frame from a high-speed motion picture showing a commercial hearing protector leaving a dummy's head 25 to 40 ms after being exposed to a 190 dB impulse.

measured reduction of the modified muff was approximately 15 dB versus the peak reduction of 8 dB. While the use of A-weighted energy provides somewhat higher values for attenuation, there is still a large gap as expected. We believe that some of this gap is due to the fact that A-weighting does not discount the low frequency sufficiently for impulse noise. A study by Patterson and Hamernik does demonstrate that the weighting for impulse noise may need to discount frequencies below 1 kHz very heavily.<sup>4</sup>

Because the NRR procedures are based on A-weighted reduction, we would expect NRR not to work well. The noise reduction rating of the modified muff is essentially zero. This should not be surprising. With its amplification at 200-250 Hz, it may be more of a hazard to wear this intentionally degraded muff in broadband noise than not wearing it. However, in the case of high levels of impulse noise, in which waveforms are similar to the waveforms depicted in Figure 1, this degraded protector is doing an outstanding job in protecting hearing.

Several caveats are in order. As shown in Figure 3, performance of a protector at these high levels is not cut and dry. In Figure 3, the muff (which is not the RACAL muff) has completely come off the ear from a 190-dB impulse. For one nonreverberant impulse, this would not be a problem as the impulse is gone by the time the muff moves off the head. For multiple impulses or for reverberant impulses, this may not be true. It is easy to visualize a second impulse

occurring right at the time the muff temporarily separates from the head. It should, also, be remembered that our results are for one type of waveform. At this time, we cannot be certain of the results for waveforms that vary significantly in duration or level from the waveforms we have used. Finally, 2 of the 57 subjects exhibited a TTS in excess of 25 dB when wearing a modified muff. For these two sensitive individuals, the protection needed to be 3 to 12 dB more in order to reduce the TTS to less than 25 dB.

### Conclusion

The use of peak levels under hearing protectors overestimates the hazard from high intensity, low frequency impulse noise. Thus, the use of peak level reduction as a measure of hearing protection underestimates the protection given. The use of NRR to estimate protection from high-intensity impulses also provides an underestimate. A-weighted energy is a step in the right direction, but its use still underestimated the performance of the hearing protectors used in our study.

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